

add this
numbering

TITLE OF THE INVENTION

DISPLAY DEVICE AND METHOD OF MANUFACTURING THE SAME

BACKGROUND OF THE INVENTION

5 ~~1. Field of the Invention~~

~~[0001]~~

The present invention relates to a display device, which utilizes an emission of electrons into a space which is in a state, and a method of fabrication thereof. and, more particularly, the invention relates to a display device having a high performance and a high reliability, which can control the position and the size of electron sources, and, at the same time, can prevent the deterioration of characteristics of the electron sources, and a fabrication method thereof.

~~[0002]~~

15 ~~2. Description of the Related Art~~

As a display device which exhibits ~~the~~ high brightness and ~~the~~ high definition, color cathode ray tubes have been widely used conventionally. However, along with the recent, desire ~~request~~ for ~~the higher quality of images of~~ information processing that is capable of providing images of higher quality equipment or television broadcasting, the demand for planar displays (panel displays) which are light in weight and require a small space, while also exhibiting a high brightness and a high definition, of such panel display devices has been increasing. As typical examples, liquid crystal display devices, plasma display devices and the like developed have been more put into practice. ~~Further,~~ particularly, as display

^{provide a}
devices which ~~can realize the~~ higher brightness, it is expected
that various ^{other} kinds of panel-type display devices, including a
display device which utilizes an emission of electrons from
electron sources into a vacuum (hereinafter referred to as "an
5 electron emission type display device" or "a field emission type
display device") and an organic EL display ^{device} which is characterized
by low power consumption, will be put into practice.

~~[0003]~~

Among ~~such~~ panel type display devices, ^{such} as the
10 above-mentioned field emission type display device, a display
device having an electron emission structure which was ^{developed} ~~invented~~
by C. A. Spindt et al (for example, see USP 3453478 ~~specification~~),
a display device having an electron emission structure of a
metal-insulator-metal (MIM) type, a display device having an
15 electron emission structure which utilizes an electron emission
phenomenon based on a quantum theory tunneling effect (also
referred to as ^a "surface conduction type electron source", see
Japanese Unexamined Patent Publication 2000-21305, for example),
and a display device which utilizes an electron emission
20 phenomenon having a diamond film, a graphite film and carbon
nanotubes and the like have been known.

~~[0004]~~

Fig. 11 is a cross-sectional view showing one
~~constitutional~~ example of a known field emission type display
25 device. Fig. 12(a) and Fig. 12(b) are ^{diagrams} ~~explanatory views~~ showing

^{an}
~~a constitutional~~ example of an electron source of one pixel and
 a control electrode which controls ^{the} ~~an~~ electron emission quantity
 of the electron source in the field emission type display device
 shown in Fig. 11, ~~wherein Fig. 12(a) is a side view and Fig.~~
 5 ~~12(b) is a plan view.~~ The field emission type display device
 is constituted such that, between inner peripheries of both ~~a~~
 a back panel 100, ^{having} ~~which forms~~ field emission type electron sources
 and control electrodes, ^{formed} ~~on an inner surface thereof,~~ and a face
 panel 200, ^{having} ~~which includes~~ anodes and fluorescent material layers, ^{formed}
 10 on an inner surface thereof which faces the back panel 100 in
 an opposed manner, a sealing frame 300 is ^{inserted and} ~~sealed by insertion~~
 so as to ~~set a pressure of~~ ^{create} an inner space, ^{which is} defined by the back
 panel 100, the face panel 200 and the sealing frame 300, ^{The pressure of this inner space}
 to a value lower than ^{the} ~~an~~ external pressure, ^{is created} ~~or to create a vacuum in~~
 15 the inner space ^{both conditions will be simply a stable} (hereinafter referred to as "vacuum").

~~{0005}~~

The back panel 100 includes a plurality of cathode lines
^{disposed thereon}
 2, having electron sources, and control electrodes 4, which are
^{and to be separated therefrom}
 configured to cross the cathode lines 2, by way of insulating
^{and, these elements are supported}
 20 layers 3, on one surface of a back substrate 1, which is preferably
 made of glass or ceramics. ~~Then,~~ ^{applied} In response to ^a ~~the~~ potential
 difference, between the cathode line 2 and the control electrode
 4, ^{the} ~~an~~ emission quantity (including turning on and off, ^{of}
^{that are} emission) of electrons, emitted from the electron source is
 25 controlled. Further, the face panel 200 includes anodes 7 and

fluorescent materials 6, ^{supported} on one ^{surface} ~~face~~ of a face substrate 5, ^{that is} made of a light transmissive material, such as glass. The sealing frame 300 is fixed to the inner peripheries of the back panel 100 and the face panel 200 using an adhesive material, such as frit glass. The inside ^{space that} ~~which~~ is formed ^{by} ~~among~~ the back panel 100, the face panel 200 and the sealing frame 300 is evacuated at a degree of vacuum of 10^{-5} to 10^{-7} Torr, for example. ^{The} ~~a~~ gap between the back panel 100 and the face panel 200 is held by gap holding members 9.

10 ~~00006~~

The insulating layers 3 are interposed between the cathode lines 2, which are formed on the back substrate 1 of the back panel 100, and the control electrodes 4, which cross the cathode lines 2 and apertures (grid holes) 4a, are formed in respective crossing portions ^{or regions} of the control electrodes 4. On the other hand, the electron sources 2a are formed on the above-mentioned crossing portions ^{in corresponding regions} of the cathode lines 2, while the insulating layer 3 is removed at portions of the cathode lines 2 which correspond to the apertures 4a formed in the control electrodes 4. The apertures 4a allow the electrons emitted from the electron sources 2a to pass therethrough to the anode side.

~~00007~~

The above-mentioned electron sources are, ^{constituted} for example, ~~constituted~~ of carbon nanotubes (CNT), diamond-like carbons (DLC) or other field emission cathodes. Here, as the electron

sources, sources which use carbon nanotubes (hereinafter referred to as ^a"CNT") are ^{employed}~~shown~~. As shown in Fig. 12(a) and Fig. 12(b), the electron source 2a is arranged right below the aperture 4a of the control electrode 4. Although one electron source 2a is allocated to each ~~one~~ pixel in Fig. 12(a) and Fig. 12(b), ^{it is also possible to allocate} a plurality of electron sources 2a ~~may be allocated~~ to one pixel.

~~FIG. 13~~

Fig. 13(a) and Fig. 13(b) are ^{diagrammatic}~~explanatory~~ views of a display device in which a plurality of electron sources are formed per one pixel ~~and correspond to Fig. 12(a) and Fig. 12(b), wherein Fig. 13(a) is a side view and Fig. 13(b) is a plan view. That is, Fig. 13(a) and Fig. 13(b) show~~ ^{an arrangement in} ~~the constitution~~ which ~~form~~ ^{are formed} a plurality of small electron sources and small apertures per one pixel. Here, a plurality of small apertures 4a1 to 4aN are formed in the control electrode 4 and a plurality of small electron sources 2a1 to 2aN are formed on the cathode line 2 at positions corresponding to the respective small apertures. The electrons irradiated from the back panel 100 impinge on the fluorescent material ^{that is} 6 ^{formed} on the face panel 200, which faces the back panel 100 in an opposed manner. Then, light which responds to ^{the} light emitting property of the fluorescent material 6 is irradiated to the outside of the face panel 200 so that the ^{structure} ~~constitution~~ functions as a display device.

25 ~~FIG. 13~~

Fig. 14 is a ~~schematic~~ ^{diagrammatic} cross-sectional view ~~for explaining~~ ^{showing} another ~~constitutional~~ example of a known field emission type display device which includes one electron source and one aperture per one pixel. Further, Fig. 15 is an enlarged cross-sectional view of ^{the} a portion indicated by A in Fig. 14. In Fig. 14 and Fig. 15, reference symbol 100 indicates a back panel, reference symbol 200 indicates a face panel and reference symbol 300 indicates a sealing frame. The back panel 100 includes cathode lines 2, which have electron sources 2a, ^{disposed thereon} and control electrodes 4, which are provided in an insulated manner ^{relative to} ~~from~~ the cathode lines 2 or an inner surface of the back substrate 1. In this example, the control electrodes 4 are held in ^{such a way} ~~in a state~~ that the above-mentioned insulating layer 3 ^{therebetween} is not interposed. Further, on an inner surface of ^{the} a face substrate 5, which constitutes the face panel ²⁰⁰ ~~100~~, fluorescent materials 6 and anodes 7 are formed in the same manner as ^{provided in} the previously-mentioned display devices.

~~{0010}~~

The control electrode 4 has ^{the} ~~a~~ function of controlling ^{the} emission of electrons (pulling out of electrons) from the electron source 2a, which is arranged on the cathode line 2. Further, in place of the control electrode 4, or in addition to the control electrode 4, it may be possible to adopt ^{on} ~~the~~ a constitution in which ^{another} ~~other~~ electrode is provided for applying a potential which converges electrons to the fluorescent material

6. Although the fluorescent material 6 is formed on the anodes 7 in Fig. 14, ^{it is possible to arrange} ~~there also exists the constitution in which the~~ ^{so that it} anode 7 covers the fluorescent material 6. Further, ^{it is possible to provide} ~~there also exists the constitution which provides~~ a light shielding layer (black matrix) between the neighboring fluorescent materials 6. The back panel 100 and the face panel 200 are laminated to each other by a sealing frame 300 and ^{the} ~~a~~ space defined between them is sealed in a vacuum.

~~[0011]~~

10 As shown in Fig. 15, ^{that are} ~~electron~~ sources 2a are formed on ^{on} ~~the~~ cathode lines 2 provided ~~to~~ the back panel 100. The electron source 2a is formed of an electron emitting material which efficiently generates electrons in response to an electric field applied between the cathode line 2 and the control electrode

15 4. With respect to a conductive material, in general, the sharper ^{the} ~~the~~ shape of outside edges thereof which are exposed ^{to} ~~in~~ the electric field, ^{will be the} ~~the~~ ^{exhibited by the conductive material} ~~the conductive material~~ exhibits the higher electron emitting performance. Accordingly, by adopting a fiber-like (rod-like) conductive material, it is possible to realize ^a ~~the~~ highly efficient electron emission. ^{example} As one ~~of~~ such electron emitting materials, the above-mentioned CNT exists.

~~[0012]~~

When ^a ~~the~~ fiber-like conductive material is used as the material of the electron sources 2a, it is necessary to fix the conductive fibers on the cathode lines 2. Here, ^{an} ~~the~~ ^{of how this is done} explanation

^{will be}
~~is~~ made with respect to a case in which ^a~~the~~ CNT is used as the
fiber-like conductive material. ^A~~The~~ CNT is an extremely fine
needle-like carbon compound. ^{it is} In a strict sense, ^a a hollow
substance in which a planar structure called graphene, which is
5 formed of carbon atoms arranged in a hexagonal shape, is arranged
in a cylindrical shape and is closed and has a diameter ^{on a} ~~of~~ nanometer
scale. By arranging ^a ~~the~~ CNT on the cathode line so as to use
the CNT as ^{an} ~~the~~ electron source, it is possible to obtain ^{an} ~~the~~
efficient electron emission. In arranging the CNT on the cathode
10 line, there ^{is a} ~~has been~~ known ~~a~~ method in which an electrode paste,
which is formed by mixing the CNT together with a conductive
filler, such as silver or nickel, is applied to the cathode line
to form an electron source layer, and, thereafter, the electron
source layer is ^{so as} baked ^{so as} to be fixed to the cathode line. Here,
15 ^{the following} ~~the following~~ ^{represent examples} ~~represent examples~~ publications, which disclose the related art on this type of
display device, ~~for example,~~ ^{and} Japanese Unexamined Patent
Publication 11-144652, ^A Japanese Unexamined Patent Publication
2000-323078 ~~and the like are named.~~

20

SUMMARY OF THE INVENTION

~~{0013}~~

In the above-mentioned conventional field emission type
display device, electrons emitted from the electron sources ^A 2a
pass through the apertures ^A 4a and impinge on the fluorescent
25 material 6 of the anodes ^A 7 and excite the fluorescent material

so as

6 to emit light and ^{produce} ~~to perform~~ a display. Accordingly, the field emission type display device provides ^{an} ~~the~~ excellent ^{design} ~~constitution~~ which possesses ~~the~~ excellent characteristics, such as ^{the ability to produce a display of} high brightness and high definition, and ^{it constitutes} ~~provides~~ a planar display ~~device~~

5 which is light-weight ~~and~~ and requires a small space for installation. However, in spite of such ~~an~~ excellent ^{characteristics} ~~constitution~~, the display device still has drawbacks to be solved.

That is, ^{some of} the electrons emitted from the electron source 2a ^{tend to} flow into the control electrode 4, ^{which causes the} ~~and hence~~ display efficiency ^{to be} ~~is~~

10 lowered. Further, when the control electrode 4 is made of a metallic material, it is necessary to ^{address the} ~~solve~~ problem ^{of} heat dissipation, besides the lowering of ^{the} display efficiency.

[0014]

^{More particularly}

^{Further}, it is difficult to ensure ^{proper} ~~the~~ alignment of the 15 electron source 2a and the aperture 4a corresponding to the electron source 2a, and this eventually ^{leads to} ~~promotes~~ the above-mentioned lowering of ^{the} display efficiency. Further, ^a ~~the~~

CNT is deteriorated and dissipated due to heating during ^{the} fabrication steps; and, hence, a sufficient electron emission

20 quantity cannot be obtained, and the formation of ^{an} ~~the~~ electron source ^{that is} capable of uniformly emitting electrons is difficult.

^{Thus} ~~In this manner~~, ~~the related art is not yet sufficient to put~~

^{this type of} ~~the display device~~ ^{has not been put} ~~into practice with respect to~~ ^{as a result of} these drawbacks and the drawbacks ^{which} ~~constitute~~ ^{problems} ~~tasks~~ to be solved.

25 [0015]

Accordingly, it is an object of the present invention to provide a display device ⁱⁿ which ~~can solve~~ the above-mentioned ~~drawbacks can be solved~~ tasks of the related art and can exhibit ^a high-performance ⁱⁿ electron emission ^{can be exhibited} characteristic and can ~~prevent the~~ deterioration of characteristics of electron sources ^{the} and hence, ^{the} ~~can be prevented~~ whereby ^a ~~can exhibit the~~ high reliability and ^{of use can be achieved} long lifetime.

~~[0016]~~

To achieve the above-mentioned object, the display device according to the present invention is characterized by ^a ~~the~~ constitution in which a plurality of small electron sources and small apertures are provided to each pixel, and the small electron sources include boron (B). ^{The display device of the present invention} and also is characterized by the acquisition of alignment of the small electron sources with the small apertures corresponding to the small electron sources, by the acquisition of ^a relative relationship between areas of the small electron sources and areas of the small apertures corresponding to the small electron sources, and by the suppression of the dissipation of ^{the} CNT caused by heating during ^{the} fabricating steps. ^{Examples of the} ~~To enumerate~~ basic constitution of the present invention ~~they~~ are as follows.

~~[0017]~~

(1) The display device according to the present invention is provided with a back panel which includes a plurality of cathode lines, a plurality of electron sources which are arranged on the plurality of ~~respective~~ cathode lines, control electrodes

which are arranged to face the cathode lines in an opposed manner and control an emission quantity of electrons from the electron sources, and a back substrate which holds the cathode lines, and a face panel which includes anodes and fluorescent materials.

- 5 The control electrodes include [^] a plurality of small apertures which allow electrons emitted from the electron sources to pass therethrough to the face panel side at ^{respective} regions which ~~respectively~~ face ~~the~~ each electron source, and each respective electron source is divided into a plurality of small electron sources
- 10 corresponding to the plurality of respective small apertures, ^{provided in each region} and boron (B) is contained in the small electron sources. Boron (B) is arranged on control-electrode-side surfaces of the small electron sources or on cathode-line-side surfaces of the small electron sources. Alternatively, boron (B) may be arranged on
- 15 surfaces of the cathode lines with respect to a plurality of small electron sources in common.

~~[0018]~~

- In this manner, by arranging the small electron sources containing boron corresponding to the small apertures formed
- 20 in the control electrode, the inflow of the electrons to the control electrode can be reduced, whereby it is possible to obtain
- ^a ~~the~~ display device which has ^{an} excellent electron emission characteristic and ^{in which} ~~prevents the~~ deterioration of property of electron sources, ^{can be prevented.} ~~and~~ ^{the display device} hence can exhibit ~~the~~ high definition, high
- 25 performance and high reliability. Here, the area of the small

to be
electron source is set smaller than the area of the small aperture
which corresponds to the small electron source.

~~400191~~

Due to such a constitution, the electrons which are
5 radiated from the small electron sources pass through the small
apertures in the anode direction without wasting ~~the~~ electrons;
and, hence, it is possible to obtain images of high brightness
with low power and, at the same time, ~~a drawback on~~ the problem of heat dissipation
of the control electrode can be solved.

10 ~~400201~~

(2) The display device according to the present invention is
provided with a back panel which includes a plurality of cathode
lines, a plurality of electron sources which are arranged on
the plurality of ~~respective~~ cathode lines, control electrodes
15 which are arranged to face the cathode lines in an opposed manner
and control an emission quantity of electrons from the electron
sources, and a back substrate which holds the cathode lines, and
a face panel which includes anodes and fluorescent materials.
The control electrodes include a plurality of small apertures
20 which allow electrons emitted from the electron sources to pass
therethrough to the face panel side at respective regions thereof which
~~respectively~~ face ~~the~~ each electron source, and each respective
electron source is divided into a plurality of small electron
sources corresponding to the plurality of respective small
25 provided in each region apertures, and boron (B) is contained in the small electron

sources and the control electrodes. The control electrodes are made of a metal material.

~~[0021]~~

Due to such a constitution, the surfaces of the control electrodes are covered with boron (B); and hence, an undesired emission (grid emission) of electrons from the surfaces of the control electrodes can be suppressed, and, at the same time, ~~a drawback on the~~ ^{problem of} heat dissipation of the control electrodes can be solved.

10 ~~[0022]~~

(3) Further, the display device according to the present invention is provided with a back panel which includes a plurality of cathode lines, a plurality of electron sources which are arranged on the plurality of ~~respective~~ cathode lines, control electrodes which are arranged to face the cathode lines in an opposed manner and control an emission quantity of electrons from the electron sources, and a back substrate which holds the cathode lines, and a face panel which includes anodes and fluorescent materials. The control electrodes include [^] a plurality of small apertures which allow electrons emitted from the electron sources to pass therethrough to the face panel side ^{respectively} at regions which ~~respectively~~ face ~~the~~ each electron source, and projecting portions which extend to the back substrate side at portions which differ from portions which face the cathode lines.

25 Each electron source is divided into a plurality of small electron

sources corresponding to the plurality of respective small ~~provided in each region~~ ^{designating} apertures, and ~~assuming~~ a distance between top surfaces of the small electron sources and bottom surfaces of the small apertures as "a" and a distance between inner surfaces of projecting portions and a side face of the small electron source closest to the inner surfaces of projecting portions as "b", a relationship $b \geq 2a$ is established. One end~~s~~ of the projecting portions ~~are~~ ^{is} brought into contact with the back substrate.

~~FIG. 23~~

10 Due to such a constitution, the dielectric strength property can be enhanced and the display efficiency is enhanced by suppressing the inflow of electrons into the control electrodes, ~~and~~ ^{so that} the control electrodes can be supported in a more stable manner ^{by} being supported by the projecting portions.

15 ~~FIG. 24~~

(4) The fabrication of the above-mentioned display device according to the present invention includes a step ^{of} ~~for~~ forming a plurality of cathode lines on a back substrate, a step ^{of} ~~for~~ forming a plurality of electron sources to each cathode line, 20 a step ^{of} ~~for~~ adhering boron (B) to respective electron sources by way of masks, each of which has a plurality of small openings corresponding to each electron source, and a step ^{of} ~~for~~ forming portions of each electron source which correspond to the small openings and to which the boron (B) is adhered into small electron 25 sources by heating each electron source.

~~[0025]~~

The control electrodes can be used as ~~the~~ masks and the electron sources ~~are~~ heated at a temperature of equal to or more than 450°C. By preventing the dissipation of the fiber-like
5 conductive material, such as CNT, which constitutes the electron source, it is possible to obtain a sufficient electron emission quantity. Further, it is possible to constitute the electron
source which emits the electrons uniformly, and, at the same time,
it is possible to obtain ~~the~~ ^adisplay device which hardly suffers
10 from ~~the~~ deterioration of the electron emission characteristic and, hence, enjoys the long lifetime. Further, the alignment between the small electron sources and the small apertures is
ensured, and, hence, the display efficiency can be enhanced.

~~[0026]~~

15 With the use of this method, the heating operation is facilitated, and, hence, by preventing the dissipation of the
fiber-like conductive material, such as CNT, which constitutes the electron source, it is possible to obtain a sufficient
electron emission quantity. Further, it is possible to
20 constitute the electron source which emits the electrons uniformly, and, at the same time, it is possible to obtain the
display device which hardly suffers from ~~the~~ deterioration of
the electron emission characteristic and, hence, enjoys ~~the~~ ^along
lifetime.

25 ~~[0027]~~

It is needless to say that the present invention is not limited to the above-mentioned constitutions and the constitutions of embodiments ^{to be} described later, and various modifications are conceivable without departing from the technical concept of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a developed perspective view of ^{a representative} ~~an essential~~ part ~~for explaining the constitution~~ of one embodiment of a field emission type display device according to the present invention.

Fig. 2 is an enlarged schematic cross-sectional view of ^{the shown} ~~an essential~~ part in Fig. 1.

Fig. 3(a) to Fig. 3(g) are enlarged cross-sectional views of ~~an essential part for explaining constitutional~~ examples of an electron source ^{for use in} ~~of~~ the embodiment of the field emission type display device according to the present invention.

Fig. 4 is a cross-sectional view of ^a ~~an essential~~ part of ~~illustrating a step in the method of~~ a display device ~~for explaining a fabrication method~~ of the field emission type display device according to the present invention.

Fig. 5 is a cross-sectional view of ^a ~~an essential~~ part of ~~illustrating a further step in the method of~~ a display device ~~for explaining a fabrication method~~ of the field emission type display device according to the present invention.

Fig. 6 is a ~~schematic~~ cross-sectional view of ^a ~~an essential~~ part of a display device ~~illustrating a further step in the method of~~ ~~for explaining a fabrication method~~ of the field emission type display device according to the present

invention.

Fig. 7 is a cross-sectional view of ^a ~~an essential~~ part of ~~illustrating a further step in the method of~~ a display device ~~for explaining a fabrication method~~ of the field emission type display device according to the present invention.

5 Fig. 8 is a cross-sectional view of ~~an essential part for explaining the constitution of~~ another embodiment of the field emission type display device according to the present invention.

Fig. 9 is a ^{diagrammatic} ~~schematic~~ perspective view ^{showing} ~~for explaining~~ one example of the holding structure for holding a given distance
10 between a back substrate and a face substrate of the field emission type display device according to the present invention.

Fig. 10 is an ^{equivalent circuit diagram showing} ~~equivalent circuit for explaining~~ one example of a ^{driving} ~~driving~~ method of a display device according to the present invention.

15 Fig. 11 is a cross-sectional view ^{showing an} ~~for explaining a constitutional~~ example of a conventional field emission type display device.

Fig. 12(a) ^{is a side sectional view} and Fig. 12(b) ^{is a top plan view} ~~are explanatory views~~ of ^{an} ~~constitutional~~ example of an electron emitting source and a
20 control electrode for controlling ^{the} ~~an~~ electron emission quantity in one pixel of ^a ~~the~~ conventional field emission type display device.

Fig. 13(a) ^{is a side sectional view} and Fig. 13(b) ^{is a top plan view} ~~are explanatory views~~ corresponding to Fig. 12(a) and Fig. 12(b) in which a plurality
25 of electron sources of the conventional field emission type

display device are formed per one pixel.

Fig. 14 is a ^{diagrammatic} ~~schematic~~ cross-sectional view ^{showing} ~~for explaining~~ another ~~constitutional~~ example of ^a ~~the~~ conventional field emission type display device.

5 Fig. 15 is an enlarged cross-sectional view showing a portion ^{within the circle} ~~indicated by~~ A in Fig. 14.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

~~100201~~

10 Preferred embodiments of the present invention ^{will be} ~~are~~ explained in detail hereinafter in conjunction with ^{the} drawings which show these embodiments. Fig. 1 is a developed perspective view showing ~~an essential part for explaining the constitution~~ ^a ~~of~~ one example of ~~the~~ field emission type display device according to the present invention, wherein parts which are identical with the parts shown in the previously-mentioned drawings and parts which have ~~the~~ identical functions ^{identified by the} ~~as those are given~~ same symbols. ^{The field emission type display device includes} In Fig. 1, ^{1 on which there are} ~~reference symbol 1 indicates~~ an electron-source-side back substrate, ² ~~reference symbol 2 indicates~~ cathode lines which hold electron sources ^{2a} ~~reference symbol 2a indicates~~ electron sources. The electron sources 2a are arranged on a surface of ^{each} ~~the~~ cathode line 2 at a plurality of positions spaced apart from each other with a given interval, and each electron source 2a is constituted of ~~a mass of~~ a plurality of small electron sources 25 2an. The plurality of small electron sources 2an are formed

on a surface of the cathode line 2 which is formed by preliminarily ^{by} printing and baking a silver paste in a state ^{in which} ~~that~~ the small electron sources 2an contain silver (Ag), CNT and boron (B), while the electron source 2a contains boron (B).

5 ~~10079~~

The small electron sources 2an are formed by a method ⁱⁿ which ^{are formed} ~~forms~~ the small electron sources 2an by baking an Ag-B-CNT paste, for example, ^{by} or a method which separately adheres boron (B) or the like. Further, the reference symbol 4 indicates control

10 electrodes (metal grids) formed of a metal plate. A plurality of control electrodes 4 are arranged in a spaced-apart manner at a given interval in ^a ~~the~~ direction orthogonal to ^{the} ~~the~~ cathode lines 2. A plurality of apertures 4a are formed in and arranged on each control electrode 4 at positions corresponding to the

15 respective electron sources 2a. Each aperture 4a is constituted of a mass of small apertures 4an, ^{provided a} in number which corresponds to the number of the above-mentioned plurality of small electron

sources 2an. Each small aperture 4an has an area which is substantially equal to ^{the} ~~an~~ area of each small electron source ^{thereby} 2an corresponding ~~to each small aperture 4an~~ and they are

20 substantially aligned with each other. Further, a face-panel-5-side surface of ^{each} ~~the~~ control electrode 4 is covered with a layer containing boron (B) (not shown in the drawing).

~~10030~~

25

~~Further, the reference symbol 4b indicates~~ ^{each control electrode 4 is provided with} projecting

portions ^{4b} and these projecting portions 4b are positioned ~~at a~~
substantially ^{at the} center between the apertures 4a and ^{they} project toward
the back substrate 1 side. ^{The} distal ends of the projecting portions
4b are adhered to the back substrate 1 between cathode lines
5 2 by way of an adhesive agent, such as glass frit or the like
(not shown in the drawing). ^{The} distance between the small
apertures 4an and the small electron sources 2an is defined by
the projecting portions 4b and is set to approximately 25 μ m in
this embodiment. Further, although the control electrodes 4
10 may preferably be made of an iron alloy (for example, 42%Ni -
6%Cr - balance Fe), the material of the control electrodes 4
is not limited to such a material.

~~[0031]~~

It is preferable to form the small apertures 4an by etching
15 from ^{the} a viewpoint of accuracy. Further, it is also possible to
form the projecting portions 4b by etching. Still further, it
is also possible to simultaneously form the small apertures 4an
and the projecting portions 4b from both surfaces by etching.
In the ~~constitution of the~~ embodiment shown in Fig. 1, one pixel
20 is constituted of a plurality of small electron sources 2an and
a plurality of small apertures 4an corresponding ^{in number} to the plurality
of small electron sources 2an. Further, in the constitution
shown in Fig. 1, ^{as opposed to} ~~different from the~~ conventional control
electrodes which are formed by sputtering, the control electrodes
25 4 are formed by machining plate materials; and hence, ~~there arises~~

an advantageous effect^{arises in} that the control electrodes 4 can be fabricated as separate members. Still further, since the face-substrate-5-side surface of the control electrode 4 is covered with a layer containing boron (B) (not shown in the drawing), the control electrode 4 has a discharge preventing effect.

~~400321~~

Fig. 2 is a ^{diagrammatic} ~~schematic~~ cross-sectional view showing ^{an enlarged form} ~~an~~ ^{a representative} ~~essential~~ part of the display device according to the present invention ^{as} shown in Fig. 1 ~~in an enlarged form~~. Parts in the drawing which are identical to the parts shown in Fig. 1 are ^{identified by the} ~~given~~ same symbols. In Fig. 2, the respective small electron sources 2an are independently arranged ^{on the cathode line 2} at portions corresponding to the small apertures 4an ^{in the overlying control electrode 4} ~~on the cathode line 2~~. Surfaces of the small electron sources 2an and the face-panel-5-side surface of the control electrodes 4 are covered with ^a ~~layer~~ 10 containing boron (B). ^{The} distance "a" between top faces 11 of the small electron sources 2an and ^{the} ~~bottom~~ surfaces 12 of the small apertures 4an is defined by the projecting portions 4b of the control electrode 4. As described above, in this embodiment, the distance is set to approximately 25 μ m. Further, the distance "b" between the projecting portion 4b and the small electron source 2a closest to the projecting portion 4b is set to a size ^{in which} which maintains the relationship ~~that~~ the distance "b" is twice or more larger than the distance "a", that is, $b \geq 2a$.

~~[0033]~~

By maintaining the ^{above-described} relationship between the distance "a" and the distance "b", it is possible to make it difficult for an undesired current to flow in the control electrode 4, and hence, the display efficiency is enhanced. Further, in this embodiment, ^{the} ~~an~~ area of the top face 11 of the small electron source 2a is ^{to be} ~~the~~ set equal to or smaller than ~~an~~ opening area of the corresponding small aperture 4a, and hence, the inflow of electrons into the control electrode is reduced due to the relative relationship between these areas.

~~[0034]~~

Fig. 3(a) to Fig. 3(g) are enlarged cross-sectional views ^{showing} ~~for explaining constitutional~~ examples of small electron sources 2a ^{for use in} ~~the~~ the embodiment of the display device according to the present invention. Fig. 3(a) shows ~~the constitutional~~ ^{an} example of the small electron source shown in Fig. 2, and Fig. 3(b) shows ~~the constitutional~~ ^{an} example of the small electron source 2a which ^{is formed} ~~forms~~ the layer 10 containing boron (B) on the cathode-line-2-side thereof. ^{of Fig 3(b)} ~~The constitutional~~ example is characterized by preliminarily forming the layer 10, having ~~the~~ ^{the} substantially same area as the small electron source 2a and containing boron (B), at a position on the surface of the cathode line 2 where the small electron source 2a is to be formed and overlapping the small electron source 2a on the layer 10 so as to prevent ~~the~~ ^{the} dissipation of a fiber-like conductive material,

such as CNT, which constitutes ~~an~~^{the} electron source.

~~[0025]~~

Fig. 3(c) shows ~~the constitutional~~^{an} example of the small electron source 2an, wherein the layers 10 containing boron (B) are formed on ^{both} the front and back surfaces of the small electron source 2an. Besides the effect ^{of} preventing ~~the~~ dissipation of the conductive material, ^{effect} which is obtained in the same manner as the above-mentioned constitutional example shown in Fig. 3(a) and Fig. 3(b), this constitutional example also has an advantageous effect ⁱⁿ that it is possible to facilitate the formation of ~~the~~ small electron sources 2an of high accuracy by ^{carrying out} ~~exercising~~ the fabrication method ^{to be} described later. Fig. 3(d) to Fig. 3(g) show ~~the constitutional~~ examples of the electron source 2a in which the layer 10 containing boron (B) is preliminarily formed on the front surface of the cathode line 2 and the small electron source 2an is formed on the layer 10. Here, the layer 10 containing boron (B) can be formed by mixing boron (B) into a paste at the time of forming the cathode line 2 per se. Fig. 3(e) shows ~~the constitutional~~^{an} example of the small electron source 2an, wherein the layer 10 containing boron (B) is formed on the front surface and the back surface of the small electron source 2an, ^{which} ~~and~~ also has an advantageous effect substantially equal to the advantageous effect obtained by the constitutional example of the small electron source 2an shown in Fig. 3(c). Further, the ~~constitutional~~ example of the small

electron source 2a shown in Fig. 3(f) can also ^{provide the} ~~have an~~ advantage that the conductive material dissipation prevention effect can be further enhanced by encasing the conductive material with the layer 10.

5 ~~100367~~

In the same manner, according to the ~~constitutional~~ example of the small electron source 2a shown in Fig. 3(g), by encasing the conductive material with the layer 10 containing boron (B) and by ~~mixing~~ ^{achieving the} the conductive material and boron (B), it is possible to ~~have an~~ advantage that the conductive material dissipation prevention effect can be further enhanced. Due to the above-mentioned constitutions shown in Fig. 3(a) to Fig. 3(g), it is possible to prevent the dissipation of the fiber-like conductive material, such as CNT, which constitutes the electron source; and hence, it is possible to obtain a sufficient electron emission quantity and ~~the~~ uniform emission of electrons ~~and~~. Furthermore, the deterioration of the electron discharge property can be prevented.

~~100377~~

20

Fig. 4 to Fig. 7 are cross-sectional views ^{showing} ~~of the essential~~ part of the display device ^{during sequential steps in} ~~for explaining the fabrication method~~ of the field emission type display device according to the present invention. First of all, as shown in Fig. 4, the cathode lines 2 are formed on the back substrate 1 ^{which consists} ~~formed~~ of a glass plate, by applying a silver (Ag) paste to the back substrate 1 and by

25

baking the silver paste. Thereafter, a paste for electron sources made of a material containing CNT and conductive fillers, such as silver (Ag) or the like, is printed on the cathode lines 2 and is heated at a temperature in a range of 300 to 350°C so as to decompose ^{the} organic binders in the paste for electron sources, thus forming an electron source layer 13.

~~[0038]~~

Although the above-mentioned heating is not indispensable, to obtain ^a ~~the~~ remarkable boron (B) adhering effect in the succeeding step, it is desirable to decompose and eliminate the organic binders which cover the surface of the cathode lines 2. Further, in this step, it is also possible to form the electron source layer 13 by printing a paste which contains only CNT.

^P Next, as shown in Fig. 5, the control electrodes 4 are set over ^{to serve} the back substrate 1 as masks. That is, the control electrodes 4 are set such that a plurality of small apertures ^{that are} 4a are formed ^{each} in ~~the~~ control electrode 4 face the electron source layer 13, and the distal ends of the projecting portions 4b are brought into contact with the surface of the back substrate 1 ~~and~~.
Thereafter, both ~~of~~ the control electrodes 4 and the back substrate 1 are temporarily fixed to each other.

~~[0039]~~

^A Further, ^I In this step, after positioning both ~~of~~ the control electrodes 4 and the back substrate 1, both ~~of them~~ may be fixed to each other by heating them at a temperature in a

range of approximately 400°C to 450°C. Although the oxidation and dissipation of CNT^{will} start due to the coexistence with metal at the above-mentioned heating temperature of equal to or more than 450°C, since the fixing time using frit glass is completed

5 within approximately 10 minutes, the deterioration of the electron emission characteristic ^{involves only} ~~is of~~ a trace amount, which can be substantially ignored. To obviate the deterioration of the electron emission characteristic such that no practical problem arises, it is possible to perform fixing of both of the control
10 electrodes 4 and the back substrate 1 in a non-oxidizing atmosphere, such as a nitrogen atmosphere. Further, in this step, it is also possible to use other masks in place of the control electrodes 4. It is also effective to use exclusive-use masks by taking mass productivity into consideration.

15 ~~[0040]~~

On the other hand, the use of the control electrodes 4, which are incorporated into the product as mentioned previously, has the characteristic that the alignment of the small apertures and the small electron sources corresponding to the small
20 apertures, that is, the coaxial property or the alignment of ^{the} ~~the~~ areas, ^{the} ~~the~~ shapes of the small apertures and the small electron sources corresponding to the small apertures, is facilitated. Subsequently, as shown in Fig. 6, boron (B) is scattered from a vapor deposition source 14. The scattered boron (B) material
25 14a passes through the above-mentioned face-substrate-5-side

surface of the control electrode 4 and the small apertures 4an and is adhered to respective surface portions of the electron source layer 13, which ^{will} become the small electron sources 2an, and forms the layer 10 containing boron on these surfaces. ^{the} A method for scattering boron (B) may be a conventionally known method. Further, it is not always necessary that boron is adhered in a single form, and ^{it} may be adhered in various forms including boron oxide and boric acid. Further, it is unnecessary to remove impurities contained at the time of adhering, provided that the impurities do not remarkably impede the electron emission per se from the CNT.

~~[0041]~~

Then, the above-mentioned structure is heated at a temperature of 450°C for 30 to 60 minutes. Due to this heat treatment, the CNT in the remaining portions of the electron source layer 13, excluding the small-electron-source-2an portions which are covered with the layer 10 containing boron, are removed. That is, the small-electron-source-2an portions of the electron source layer 13, which are covered with the layer 10 containing boron, suppress the oxidation of the CNT as the adhered boron per se is oxidized to form the boron oxide and form protective layers for the CNT, and hence, the CNT remains. However, with respect to the peripheries of the electron source layer 13 which are not covered with the boron layer 10, the CNT in the whole layer or the CNT excluding the conductive fillers

is dissipated by heating, and hence, the columnar small electron sources 2an are formed, as shown in Fig. 7. Further, boron adhered to the control electrodes 4 is fixedly adhered to such portions. Here, Fig. 7 shows ^athe constitution in which the conductive fillers remain in the peripheries of the small electron sources 2an.

~~[0042]~~

Here, the heating temperature may be determined by taking the composition of the electron source layer 13 and the like into consideration. However, since no restriction is imposed on the heating temperature during the fabrication steps even when the heating temperature is 450°C or more, it is possible to sufficiently maintain the desired electron emission efficiency. Further, the CNT which is protected by boron ^{at}once exhibits the protection effect even with respect to the additional heating under atmosphere ^{conditions} which follows thereafter. Even when the heating is performed under atmosphere ^{conditions} again at a temperature of 450°C or more, the CNT exists in ^athe fiber form. Further, the deterioration of the electron emission characteristic can be obviated. This implies that the CNT exhibits ^athe resistance not only in the baking process of the printing paste, but also in the succeeding heating process of the manufacturing steps, and hence, a yield rate in the fabrication of panels and the reliability of products can be remarkably enhanced, and the lifetime of the display device can be prolonged.

~~[0043]~~

With use of

~~Due to~~ the above-mentioned fabrication method, it is possible to selectively adhere the layer 10 containing boron to the control electrodes 4 at desired positions ^{over a} ~~with~~ desired area by way of the masks. Further, by combining the CNT oxidation suppression action which boron has with the above selective adhesion of layer 10, due to their coupled effect, it is possible to attain ~~the~~ self-alignment of the small apertures 4an and the small electron sources 2a, and, at the same time, it is possible to adopt the desired heating temperature in the fabrication steps, whereby it is possible to obtain ~~the~~ excellent advantageous effects, such as the acquisition of accurate alignment of the small apertures 4an and the small electron sources 2an, the acquisition of ^a high electron emission efficiency, and ^a ~~the~~ reduction of the inflow of undesired electrons into the control electrodes. Further, with the use of the control electrodes 4 as ~~the~~ masks, not to mention the acquisition of accurate alignment, the control of areas of the small electrons sources 2an is further facilitated.

20 ~~[0044]~~

hypermetate

Fig. 8 is a ~~schematic~~ cross-sectional view of a portion of another embodiment of the field emission type display device according to the present invention, ^{and is similar to the embodiment} ~~corresponding to the portion~~ shown in Fig. 2. The ^{embodiment} ~~constitution~~ shown in Fig. 8 is characterized by ^{a reduction in} ~~reducing~~ the number of projecting portions 4b

compared to the constitution shown in Fig. 2. In this embodiment, the control electrode 4 is formed ^{to extend} ~~by striding~~ over every two cathode lines 2. Also in this constitution, in the same manner as the constitution shown in Fig. 2, ^{the} distance "a" between the top faces 11 of the small electron sources 2an and the bottom faces 12 of the small apertures 4an is defined by the projecting portions 4b of the control electrodes 4 and is ^{also} set to approximately 25μm ~~also~~ in this embodiment in the same manner as described above. Further, the distance "b" between the projecting portions 4b and the small electron source 2an closest to the projecting portions 4b is set to a size which maintains the relationship ^{in which} ~~that~~ the distance "b" is twice or more greater than the distance "a", that is, $b \geq 2a$. By maintaining this relationship between the distance "b" and the distance "a", the flow of an undesired current into the control electrodes 4 becomes difficult, and, hence, the display efficiency is enhanced. Further, although the projecting portions 4b are formed such that the control electrode 4 ^{extends} ~~strides~~ over every two cathode lines 2 in ^{an} ~~an~~ example shown in Fig. 8, by forming the projecting portions 4b such that the control electrode 4 ^{extends} ~~strides~~ over three cathode lines of three primary colors of red (R), green (G) and blue (B) for display, it is possible to ^{achieve a} ~~expect the~~ reduction of color difference.

~~{0045}~~

25

Fig. 9 is a ^{diagrammatic} ~~schematic~~ perspective view ^{showing} ~~for explaining~~ one

example of the holding structure for ~~holding~~ ^{maintaining} a given distance ^{that is} between the back substrate 1 arranged at the electron source side of the display device of the present invention and the face ^{that is} substrate 5 arranged at the fluorescent face side of the display

5 device of the present invention. Between the electron-source-side back substrate 1 on which the above-mentioned cathode lines 2, electron sources 2a and control electrodes 4 are formed and the fluorescent-face-side face substrate 5, partition walls (or spacers) 9 are interposed, and ^{the} peripheries of both substrates 1, 5 are sealed by a frame glass (not shown in the drawing) and glass frit (not shown in the drawing). This sealing is performed in the atmosphere at a temperature of 430°C. Thereafter, ^{the} space defined between both substrates 1, 5 is evacuated and is sealed in vacuum while heating the holding

15 structure at a temperature of 350°C.

~~FIG. 10~~

^{diagram showing}
Fig. 10 is an equivalent circuit ^{driving} ~~for explaining~~ one example of a ~~driving~~ method of the display device according to the present invention. In this display device, n ~~pieces of~~ cathode lines (electron source lines) 2, which extend in the y direction, are juxtaposed in the x direction. Further, m ~~pieces of~~ control electrodes (metal grids) 4, which extend in the x direction, are juxtaposed in the y direction, thus constituting a matrix of m rows and n columns together with the cathode lines 2. On ^{side and top peripheral areas} ~~peripheries~~ of the electron-source-side back substrate which

20

25

constitutes the display device, a scanning circuit 60 and a video signal circuit 50 are arranged. Respective control electrodes 4 are connected with the scanning circuit 60 at control electrode terminals 40 (Y1, Y2, ... Ym). Respective cathode lines 2 are
5 connected with the video signal circuit 50 at cathode terminals 20 (X1, X2, ... Xn).

~~[0047]~~

For every pixel^{that is} arranged at each one of^{the} crossing portions of the cathode lines 2 and the control electrodes 4 which are
10 arranged in a matrix array, ^{this is an} ~~the~~ electron source which is formed of a mass of a plurality of small electron sources containing ^{as described with reference to} boron ~~explained in~~ the above-mentioned embodiment ~~is provided~~.

In the drawing, R, G, B respectively indicate monochromatic pixels of red (R), green (G) and blue (B), each of which constitutes
15 one pixel of each color. These respective monochromatic pixels emit light^{the} corresponding to^{the} respective colors from the fluorescent materials. To the scanning circuit 60 and the video signal circuit 50, various signals for display are supplied from a host computer[^] (not shown in the drawing). Synchronizing signals
20 61 are also inputted to the scanning circuit 60. The scanning circuit 60 selects the row of the matrix of the control electrodes 4 through the control electrode terminals 40 and applies scanning signal voltages to the control electrodes 4.

~~[0048]~~

25 On the other hand, video signals 51 are inputted to the

video signal circuit 50. The video signal circuit 50 is connected to the cathode lines 2 through the cathode terminals 20 (X1, X2, ... Xn), and ^{it} selects the column of the matrix and applies voltages corresponding to the video signals 51 to the selected cathode lines 2. Accordingly, given pixels which are sequentially selected by the control electrodes 4 and the cathode lines 2 emit light in given colors, thus displaying two-dimensional images. With the use of ^a the display device which uses ~~the~~ CNT according to this constitutional embodiment as the electron source, it is possible to realize ^a the bright display device, which is operated with a relatively low voltage at high efficiency, and ^{in which} ~~can suppress the~~ display irregularities, ^{can be suppressed}

~~[0049]~~

Here, although the ^{embodiment is directed to} ~~explanation is made using~~ the CNT ^{use of} (multi-wall CNT and single-wall CNT, carbon nanotubes in a broad meaning) as the electron emission material, ^{accordance with} ~~in the embodiment~~ ^{it is possible to use that} of the present invention, any material can obtain a similar advantageous effect as the electron irradiation material provided that the material is ^{an} inorganic carbon material. As ^{an} the inorganic carbon material other than the CNT, for example, diamond, diamond-like carbon, graphite, ^{and} amorphous carbon can be used. Alternatively, a mixture of these materials, ^{also} can be ~~also~~ used as the electron irradiation material. Further, it is needless to say that the present invention is not limited to the constitutions of the above-mentioned embodiments and ^{that}

various modifications can be made within the scope of the technical concept of the present invention.

~~100501~~

As has been described heretofore, according to the typical
5 embodiment of the present invention, ⁱⁿ the display device,
^{is constituted} ~~constitutes~~ one pixel ^a by combining ~~the~~ ^a plurality of small
apertures and ^a ~~the~~ plurality of small electron sources. Due to
such a constitution, ~~the~~ small electron sources having ^a ~~the~~
desired area can be formed in ~~the~~ given regions; and, hence, the
10 inflow of electrons to the control electrodes can be reduced,
and, at the same time, ^{an} ~~the~~ alignment of the small electron sources
and the small apertures can be easily ^{achieved} ~~acquired~~. Further, the
present invention can also exhibit other advantageous effects,
such as the acquisition of ^a ~~the~~ high-performance electron emission
15 characteristic, ^{and} ~~the~~ prevention of ~~the~~ deterioration of ^{the} ~~the~~
characteristics of the electron sources, whereby ^a ~~the~~ display
device of high definition, high performance and high reliability
can be realized.

~~100511~~

20 Further, the heat resistance of the carbon nanotubes can
be enhanced; and, hence, it is possible to elevate the heating
temperature in the electron source baking step and the substrate
sealing step in the fabrication process to ^a ~~the~~ given high
temperature, whereby it is possible to realize ^a ~~the~~ display device
25 having ^a ~~the~~ long lifetime, which exhibits ^a ~~the~~ high-performance

electron emission characteristic and ^{in which} ~~can prevent the~~
^{the} deterioration of ^{can be prevented} characteristics of the electron sources.

~~{0052}~~

Further, it is possible to use a general-use heating
5 furnace (or a baking furnace) in the heating step of the
fabrication process, and this contributes to ^a ~~the~~ reduction of ^{the}
fabrication cost. Further, by also adopting heating or baking
in a non-oxidizing atmosphere in combination, the uniformity
of the electron emission can be further enhanced, whereby it is
10 possible to provide ^a ~~the~~ display device of high quality.